THE DOE–2 USER NEWS

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DOE-2: A COMPUTER PROGRAM FOR BUILDING ENERGY SIMULATION

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Table of Contents

☞ ☞ HANDS ON ☜ ☜

☞ Building Simulation '89

The proceedings from the **Building Simulation '89** conference, held in Vancouver, B.C. last September, are available from

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Fullerton, CA 92634
FAX: (714) 449-7168

Cost of the proceedings is $75.00 per copy plus $3.00 s/h within the U.S.

☞ Time To Make Travel Plans

June 9-13 — *Annual Meeting of ASHRAE*
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July 1990 — *Industrial Facilities*
Part of a Ten-Course Series on Air Conditioning Design. Sponsor: U. Wisconsin. Contact: Engineering Registration, The Wisconsin Center, 702 Langdon St., Madison, WI 53706. Phone: (608) 262-1299.

Aug 13-17 1990 — *Electronic and Direct Digital Controls*
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Aug 26-Sep 1 — *ACEEE 6th Summer Study*
to be held at Asilomar in Pacific Grove, California. Sponsor: American Council for an Energy Efficient Economy. Contact: ACEEE 1990 Summer Study, Bldg B90H, Lawrence Berkeley Laboratory, Berkeley, CA 94720.

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A MINUTE PER ZONE ON PCs

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I had a dream 3 years ago. At that time, having just converted the DOE-2.1C program to run on IBM PCs and calling the program MICRO-DOE2, I dreamed we would make a PC version of DOE-2 that would run a full 64 zones at the same speed of a VAX computer. At that time, Acrosoft was time-sharing a VAX computer from a company in Denver. Now, in January of 1990, we have just finished testing two special versions of MICRO-DOE2 (the "DX" versions) that run only on 386 computers using extended DOS and either an Intel 30387 or Weitek 1167/3167 coprocessor. These latest 386 versions of the MICRO-DOE2 family will run a full 64 zones and run **FASTER** than the VAX computer that we time-shared. To be exact, it is 58% faster with a Weitek coprocessor, and 23% faster with an Intel 30837 coprocessor. Isn't this a dream come true!

Advantages of the Extended DOS 386 Versions

a. They are a lot faster: On a COMPAQ DESKPRO 386/20e with a 30387 coprocessor, the ratio of runtime between the regular DOS version and an extended DOS version is 1.66 to 1. On the same computer with a Weitek coprocessor, the ratio grows to 2.03 to 1.

b. They take 64 zones: The Fortran compiler for the extended DOS versions can address memory locations for up to 4 giga-bytes versus the 640 kilo-bytes addressed by a regular DOS compiler. Also, with the extended DOS versions, the size of the AA/IA array in the DOE-2 program is no longer an issue. The size of the AA/IA array can be easily increased to sizes previously possible only on mini or mainframe computers.

System Requirements of the 386 Version

Computer	:	Compaq 386 or true compatibles
Operating System	:	MS DOS or PC DOS 3.0 or higher
Memory	:	3 Mega-Bytes (MB) Random Access Memory
Math Coprocessor	:	Intel 30387 or Weitek 1167/3167
Hard Disk Drive	:	20 MB
Floppy Disk Drive	:	720 Kilo-Bytes or 1.2 MB
Monitor	:	B/W or Color
Printer	:	Text Printer

Benchmark Testing of the Extended DOS Versions

The execution time of MICRO-DOE2 on a given computer will depend on a number of factors. These include the type of microprocessor and math coprocessor, the clock speed (in MHz), and, of course, the size of the BDL input (zones, walls, schedules, etc).

We picked two BDL inputs from samples that come with DOE-2.1D, and ran them with different DOS configurations/coprocessors used for MICRO-DOE2, Version 2.1D. The computer used for this benchmark testing was a COMPAQ DESKPRO 386/20e, with a 20 MHz 30386 processor.

Test Samples

Description	Zones	LOADS	SYSTEMS	PLANT	ECON	Report (pages)
BENCH02	11	1	1	1	1	13
BENCH3A	11	1	1	1	1	25

BENCH02 is the first LOAD-SYSTEM-PLANT-ECON input from SAMP02.INP

BENCH3A is the first LOAD-SYSTEM-PLANT-ECON input from SAMP3A.INP

Total Time Used (in seconds)

Description	Regular DOS w/ 30387	Extended DOS w/ 30387	Extended DOS w/ Weitek
BENCH02	1352	782	664
BENCH3A	1733	1092	852

Time Used Per Zone (in seconds)

Description	Regular DOS w/ 30387	Extended DOS w/ 30387	Extended DOS w/ Weitek
BENCH02	122.9	71.1	60.4
BENCH3A	157.5	99.3	77.5
Average	140.2	85.2	69.0

33 MHz 386 PCs vs. 20 MHz 386 PCs

The benchmark tests were conducted with a 20 MHz 386 computer. However, the fastest clock speed for 386 computers is 33 MHz. And since the runtime ratio is an inverse of computer clock speed, runtime on a 33 MHz 386 computer will be close to two-thirds of the time recorded in the benchmark tests, factoring in also the I/O processing portion of runtime. Thus, a 33 MHz 386 will only take 46 seconds per zone (69 x 2/3) with the Weitek version and 56.8 seconds per zone (85.2 x 2/3) with the Intel version. A 33 MHz 386 PC takes **LESS THAN A MINUTE PER ZONE** for an annual hour-by-hour simulation, from loads calculation through economic analysis.

Weitek 3167 vs. Intel 30387

We conducted another benchmark test comparing the Weitek 3167 extended DOS version with the Intel 30387 extended DOS version. We simply set up a batch file to run through all seven DOE-2.1D samples with both extended DOS versions. The total time used was 02:21:16 for the Weitek version and 02:52:11 for the Intel version. The runtime ratio of Weitek versus Intel was 0.82 to 1, or 1 to 1.22. This improvement of approximately 20% with a Weitek coprocessor was a bit disappointing, but not a surprise, because most calculations of DOE-2 are done with single precision calculations.

386 PC vs. VAX Computer

In a similar benchmark test in December 1986, we found the runtime ratio of an IBM AT (8 MHz) and the VAX computer we time-shared was 5.4 to 1 (average of 3 tests). Recently we found the runtime ratio of an IBM AT (8 MHz) (using the regular DOS version) and a COMPAQ DESKPRO 386/20e (using an extended DOS version) was 8.54 to 1 (Weitek) and 6.65 to 1 (30387). Correlating these two tests, the runtime ratio of a VAX and the MICRO-DOE2 386 versions are 1.58 to 1 (Weitek) and 1.23 to 1 (30387). Thus, these tests indicate that the inexpensive 386 PCs out-perform the much more expensive VAX computer.

In his book, **Thriving on Chaos**, Tom Peters criticizes the prevailing belief that "big is good; bigger is better; biggest is best." The 386 extended DOS versions of MICRO-DOE2 are proof that this belief is no longer valid.

* * * * * * * * *

Notes

1. All MICRO-DOE2 runs include runtime status displays-enhancements from Acrosoft.
2. The execution time of VAX runs is the CPU time consumed, not the turn-around time, using a *vanilla* version from Lawrence Berkeley Laboratory.

Trademarks

■ ■ ■ THE HEAT EXCHANGER ■ ■ ■

If a user is running DOE-2 and it aborts in BDL with the error message "Symbol Table Full" and/or "Exceeded Max for This Item of *n*", don't panic! The maximum number of SCHEDULEs, EXTERIOR-WALLs, WINDOWs, LAYERs, and CONSTRUCTIONs may be increased. First, make the changes below [between the ruler lines] to the end of file "DKEY.vax". Next, rebuild the file "BDLKEY.bin" by running the command file "@uvl key bdlkey". These changes are for 2.1D. **NOTE:** The maximum number INTERIOR-WALLs is 112 and cannot be increased.

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7--
*/ ------------------ start file: DKEY.vax --------------------
*IDENT DKEYbig
*/ --- allow more SCHEDULEs, EXTERIOR-WALLs, WINDOWs, LAYERs, CONSTRUCTIONs
*/ ---- allow 100 SCHEDULEs, WEEK-SCHEDULEs, 200 DAY-SCHEDULEs
*D LDLKEY.73,LDLKEY.75
1SCHEDULE           SCH         1   76    0        100.      0.0       0.0
1WEEK-SCHEDULE      W-SCH       2   75    0        100.      0.        0.
1DAY-SCHEDULE       D-SCH       3   74    0        200.      0.        0.
*D SDLKEY.263,SDLKEY.265
1SCHEDULE           SCH         1   76    0        100.      0.0       0.0
1WEEK-SCHEDULE      W-SCH       2   75    0        100.      0.        0.
1DAY-SCHEDULE       D-SCH       3   74    0        200.      0.        0.
*/ ---- allow 256 EXTERIOR-WALLs
*D LDLKEY.249
1EXTERIOR-WALL      E-W        12   20    2        256.      0.        0.
*/ ---- allow 256 WINDOWs
*D LDLKEY.275
1WINDOW             WI         14   50    3        256.      0.        0.
*/ ---- allow 64 LAYER commands
*D LDLKEY.394
1LAYERS             LA         23   24    0        64.       0.        0.
*D LDLKEY.129
*/ ---- allow 64 CONSTRUCTION commands
1CONSTRUCTION       CONS        8   22    0        64.       0.        0.
*/ ---- increase max u-names to 800
*D LDLKEY.2
$LDL                     800
*D SDLKEY.2
$SDL                     800
*/ ---- increase constants table for functions processor to 500
*/ ---  200 : lsymt  , 500 : lcont  , 1000 : llitt  , 200 : llabt
*D GTBL.35
$LDS   200  500 1000  200
*/ --- max INTERIOR-WALLS must be 112 = (900/(2*4)) , see READSS
*D LDLKEY.320
1INTERIOR-WALL      I-W        15   46    2        112.      0.        0.
*/ ------------------ end file: DKEY.vax --------------------
----+----1----+----2----+----3----+----4----+----5----+----6----+----7--
```

Modeling Complex Daylighting With DOE-2.1C

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Daylighting is often proposed as an energy conservation strategy in new commercial buildings. This paper will describe a daylighting analysis technique using some powerful and generally unused features of the DOE-2.1C computer program in combination with scale building models and/or detailed daylighting calculations. This method was used to model and analyze various daylighting options in several new utility office buildings constructed in Oregon.

Introduction

As part of a Bonneville Power Administration field test of energy efficient commercial buildings (Energy Edge Project), extensive design assistance was provided for a number of innovative new commercial buildings in the Pacific Northwest. This design assistance included funding energy and engineering consultants and analysis. One of the program requirements was hourly building modeling to determine anticipated performance of various conservation measures. Daylighting measures were significant components of two of these buildings and posed significant analysis problems. The Oregon Department of Energy (ODOE) worked closedly with building architects, engineers, and consultants on these two projects and provided both technical assistance and building modeling.

Example Buildings Using Daylighting

These two new buildings used for analysis are both central offices of publicly owned electric utilities located in Eugene, Oregon. Both utilities are strongly committed to energy conservation. The Emerald Public Utility District (EPUD) building, as shown in Fig. 1, was designed as a state-of-the-art low energy building. The EPUD building is a two story structure with over 90% of the facility incorporating daylighting. Daylighting design features include high ceilings, perimeter light shelves, fixed louver and deciduous vine shading, high clerestory windows, diffusing cloth baffles, and low ambient target light levels. The EPUD building is constructed of heavy masonry throughout with exterior insulation, hollow concrete core floors used for night flush cooling and morning heating warmup, and indirect lighting reflected from the exposed concrete ceilings.

This article was originally published in the Proceedings of the Solar Energy Society Conference held in Denver, Colorado in June, 1989.

1. **Night-Air Flush**
2. **Conditioned Air Supply**
3. **Clerestory Windows** for deep, even daylight penetration.
4. **Core-Slab Roof** for thermal mass and night air flush.
5. **Light Shelves** are used for even daylight distribution; to provide soft, ambient indirect light; they are CRT compatible; they provide task light at each desk.
6. **Finwalls** for thermal mass, structure, and privacy.
7. **Conditioned Air Return**
8. **Core-Slab Floor** for thermal mass and night air flush.
9. **Trellises and Vines** to control summer sun.
10. **Acoustic Baffles** for sound absorption.
11. **Paired Beam** for air distribution

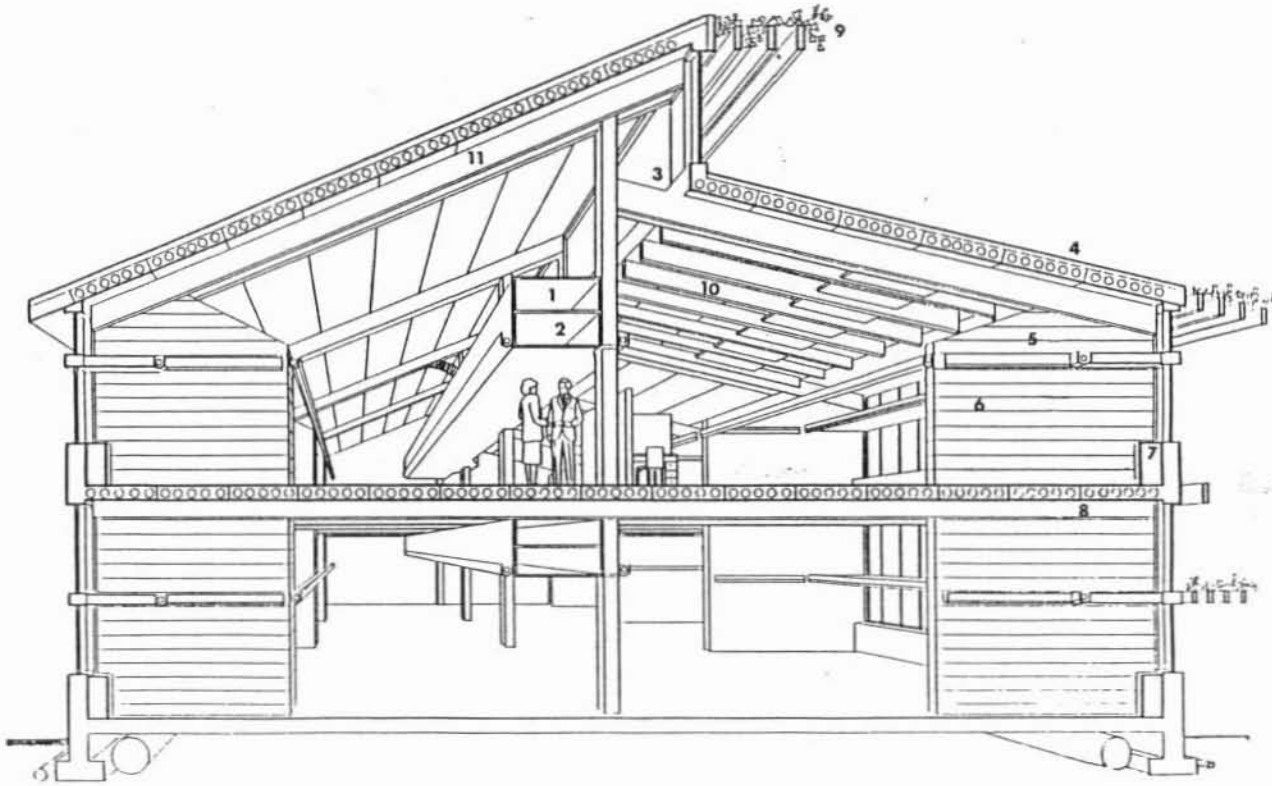
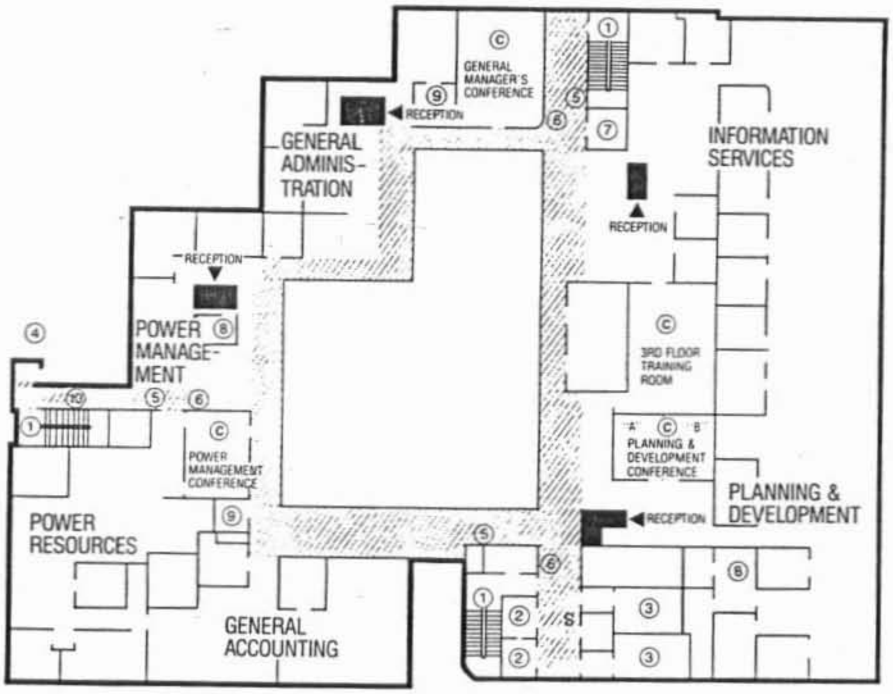


Figure 1. EPUD Building Section

The Eugene Water and Electric Board (EWEB) building is a two-building complex. The main south building is a four story office block with a central atrium with daylighting provided by north-facing sawtooth clerestory windows. The EWEB building also uses perimeter light shelves, fixed overhangs, and movable roll-down shading screens. Both the EPUD and EWEB buildings incorporate stepped dimming of light fixtures to reduce electric lighting. This is generally accomplished by turning off a bank of fluorescent bulbs in multi-lamp fixtures under computerized controls.



C Conference Rooms
1. Stairs
2. Elevators
3. Restrooms
4. Covered Outdoor Smoking Area
5. Drinking Fountain
6. Fire Ext Cabinet
7. First Aid Station
8. Copier
9. Coffee Bar
10. Bulletin Board

Figure 2. **EWEB Building Plan - Third Floor**

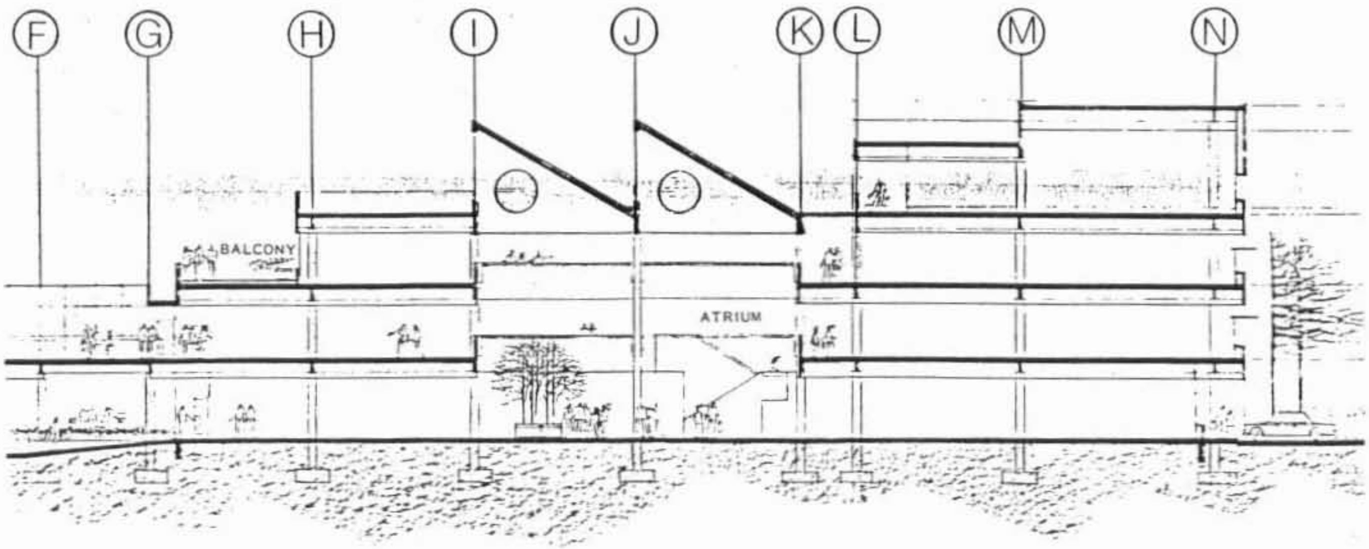


Figure 3. **EWEB Building Daylighting Test Zones**

Daylighting Analysis Limitations

Although DOE-2.1C supports daylighting better than most other hourly models, DOE-2 has the following limitations:

(1) daylighting is calculated accurately for only simple geometries;

(2) the daylit space must also contain the window or skylight; and

(3) complex or seasonal shading, baffles, and louvers cannot be easily analyzed.

DOE-2 and other similar computer programs can calculate daylighting in a space for simple geometries with side or top lighting. Daylighting calculations in DOE-2 use solar geometry for the direct component and the "split-flux" method for determining the internally reflected component of daylight. For internally reflected light (the dominant component in most building designs), the daylight transmitted through a side window is split into two parts--a downward flux onto the floor and walls below an imaginary window mid-plane and an upward flux onto the ceiling and walls above this imaginary mid-plane. The flux onto the ceiling is assumed to be spread evenly over the ceiling area. The floor flux is also treated the same but because of the low reflectance values generally assumed for floors, this floor flux doesn't have much impact. This split-flux method will generally not be accurate for deep spaces ($depth > 2 * height$). This method cannot accurately handle complex daylighting schemes using light shelves or reflective overhangs that are highly directional and force more light onto the ceiling.

A second and more severe limitation to daylighting analysis with DOE-2 is that the daylit space (HVAC zone) must contain the window or skylight providing the light. DOE-2 does not support light sharing from one zone to another. A commercial building might have a typical perimeter zone of depth 12 to 20 feet. Internal zones provided with daylighting shared from an adjacent perimeter zone can't be analyzed. A multi-story atrium providing daylighting to adjacent spaces poses a similar problem. Generally, even the atrium space cannot be analyzed properly. The EWEB building (Figures 2 and 3) has a four story central atrium space. For HVAC modeling, the floor zone of the atrium is a completely different comfort zone from the top space with the actual sawtooth clerestory windows and associated glazing/infiltration skin losses and gains.

Yet, the more commonly proposed daylighting strategies (light shelves, atria) fall into these problem analysis areas. Fortunately, DOE-2.1C introduced a powerful FUNCTION extension that may be used for daylighting analysis in these cases.

Using Functions in DOE-2.1C

The FUNCTIONS mechanism was added to the LOADS module in version 2.1C of DOE-2 to extended the program for complex designs not covered by the standard options built into DOE-2. The FUNCTIONS mechanism includes several features:

(1) the ability to access variables within the LOADS analysis program during the simulation;

(2) the ability to make new calculations using these LOADS variables for reporting and debugging;

(3) the option to replace certain calculated variables in the LOADS module; and

(4) a built-in interpreter supporting a pseudo-FORTRAN dialect for calculation purposes during the hourly LOADS simulation.

Using FUNCTIONS, a building modeler can replace the calculated value for certain variables in the LOADS module during the simulation based on other LOADS variables. To analyze complex daylighting, a user-defined FUNCTION can be designed to replace the DOE-2 calculated daylight values with data from either scale building models or much more sophisticated daylight illuminance calculation programs such as SUPERLITE. The technique used with the two example buildings was based on using scale building model studies.

During the design phase, scale models were constructed of sections through both buildings for daylight modeling. These scale models were tested under diffuse and clear sky conditions to determine daylight factors. The University of Oregon (Eugene, Oregon) has an artificial sky facility but it is limited to modeling diffuse sky conditions. For direct sun, the daylight factors were measured outside on clear days at various locations within the model with varying solar altitudes and azimuths. Based on these scale models, daylight FUNCTIONS were constructed for use in DOE-2. The daylight FUNCTION that was used is based on determining the interior light levels from daylighting by interpolating values based on solar altitude and azimuth. Two sample functions are outlined below.

The first example is for a simple north-facing perimeter space in the EPUD building with interior light shelves. A north-south building section is shown in Figure 1. In this case, the daylighting was approximated as a fixed daylight factor times the outside horizontal illuminance. This daylight factor was measured from scale model studies under overcast skies. The daylight factors measured under direct sun conditions were similar enough to the diffuse conditions that for simplicity, they were not used. The changes to the DOE-2 SPACE commands and the actual daylight FUNCTION used are shown in Figure 4.

A few comments would be helpful in understanding the overall scheme and DOE-2 input data semantics. The dollar sign ($) is used in DOE-2 input language as a comment delimiter. The internal DOE-2 daylighting calculations are enabled with the SPACE command DAYLIGHTING=YES. DOE-2 supports dividing an HVAC zone into two parts with separate daylight levels for each part. The size of each part of the HVAC zone with daylighting is not fixed by the program--the default is ZONE-FRACTION1 to be 1 (100% of the space). For DOE-2's internal daylight calculations, the location (LIGHT-REF-POINT) of the control point and the target light level (LIGHT-SET-POINT) in footcandles must be specified. The type of dimming system (LIGHT-CTRL-TYPE) must also be set. If stepped dimming is specified (as opposed to continuous dimming), then the number of fixed steps must be noted.

```
$ FIRST THE ADDITIONS TO THE SPACE COMMAND FOR DAYLIGHTING

1-NORTH-PER = SPACE
   .
   .  $ THE NORMAL SPACE COMMANDS
   .
DAYLIGHTING = YES
LIGHT-REF-POINT1 = (186,82,3)               $ LOCATION OF REF IN X,Y,Z
LIGHT-SET-POINT1 = 30                       $ SET PT IN FOOTCANDLES
LIGHT-CTRL-TYPE1 = STEPPED                  $ STEPPED DIMMING
LIGHT-CTRL-STEPS = 3                        $ OFF, 1, AND TWO BULBS ON
ZONE-FRACTION1 = 1                          $ ALL OF THE SPACE
DAY-ILLUM-FN = (*NONE*, MEAS-1-N-PER)       $ USER-DEFINED FUNCTION
..

$---DAYLIGHTING FUNCTION FOR NORTH SPACE WITH LIGHT SHELF
   FUNCTION
   NAME = MEAS-1-N-PER
   LEVEL = SPACE  ..

$ FIRST WE ASSIGNED THE LOADS VARIABLES WE WILL USE IN THE CALCULATIONS.
$ FOR CONVENIENCE, USE THE SAME NAMES BUT LIMIT TO SIX CHARACTER NAMES,
$ THE LIMIT OF PSEUDO-FORTRAN

ASSIGN  OHISKF = OHISKF                 $ HORIZONTAL ILLUMINANCE FROM
                                        $   OVERCAST PART OF SKY
        CHISKF = CHISKF                 $ HORIZONTAL ILLUMINANCE FROM
                                        $   CLEAR PART OF SKY
        HISUNF = HISUNF                 $ HORIZONTAL ILLUMINANCE FROM SUN
        ILLUM1 = DAYLIGHT-ILLUM1 ..     $ DAYLIGHT ILLUMINANCE
                                        $ AT REF. PT 1 (FOOTCANDLES)

CALCULATE  .. $ NOTE: NEXT TWO LINES MUST BEGIN IN COLUMN 7
      ILLUM1 = .80*(HISUNF+CHISKF+OHISKF)*0.036
      END
END-FUNCTION ..
----+----1----+----2----+----3----+----4----+----5----+----6----+----7
```

Note that 0.036 is the measured daylight factor from the scale model for overcast conditions. The .80 value adjusts the measured model data for losses in visible light transmission through double glazing.

Figure 4. **EPUD User-Defined Daylight Function for North Perimeter**

The daylighting function to be used in a zone (SPACE) is set with the DAY-ILLUM-FN command. DAY-ILLUM-FN is a special DOE-2 function which determines the hourly daylight illuminance and glare index at each reference point in a space. The command takes the name of a user-defined function to be called before the internal DOE-2 daylight calculations and a function to be called after DOE-2's own calculations. The special name *NONE* is an internal name for not calling a function. In our case, we insert a function to be called after the DOE-2 internal calculations so we can replace certain daylighting loads values. The same daylighting function can therefore be used by several similar zones. Although this scheme provides a great deal of flexibility, the DOE-2 internal calculations will be performed even if all their associated output values are replaced.

The actual FUNCTION to be invoked must be defined later in the input data deck after all of the other LOADS information. The current DOE-2 implementation supports up to 100 user-defined functions. A function is delimited by the FUNCTION and END-FUNCTION statement. The FUNCTION command has three parts:

(1) name and use information;

(2) an assignment section for assigning names of variables used from the simulation; and

(3) a calculation section supporting a pseudo-FORTRAN interpreter.

The function NAME assigned will be how a particular function is referenced in the DOE-2 LOADS input data. The LEVEL refers to at what "level" of the simulation this particular function applies. Functions are contained within the hourly loop of the DOE-2 simulation. Functions can apply at the entire building (BUILDING or BLDG) level, the HVAC zone (SPACE) level, or at the component level (EXTERIOR-WALL, UNDERGROUND-WALL, WINDOW, or DOOR). In our example with LEVEL = SPACE, the function would be performed within the hourly space calculation loop of the DOE-2 simulation.

Variables used within a user-defined function are declared through the use of the ASSIGN command. These local variables or table variables are limited to 1-7 character names chosen by the user (pseudo-FORTRAN). In our example, the local variables have generally been assigned the same name as the DOE-2 LOADS variable they store. The CALCULATE section begins the actual pseudo-FORTRAN statements that will be interpreted at runtime. Clearly, simulation times will increase with the number and complexity of FUNCTIONS used since these are interpreted. The typical speed of an interpreted versus compiled section of code is usually one to two orders of magnitude (10 to 100 times) slower.

The second example (Figure 5) is the more useful case illustrating daylighting affected by solar altitude. This function was used for a south-facing interior zone in the EWEB building receiving light shared from an adjacent perimeter zone with light-shelves. A sample building section is shown in Figure 3. This case illustrates using a daylighting FUNCTION based on interpolating from a table for determining the daylighting factor from solar altitude. The daylight function uses a pseudo-FORTRAN function PWL(table,value).

```
$--DAYLIGHTING FUNCTION FOR INTERIOR SOUTH SPACE
   FUNCTION
   NAME = MEAS-2-SOUTH
   LEVEL = SPACE  ..

$ ASSIGN LOCAL VARIABLES USED

ASSIGN      PHSUND = PHSUND                   $ SOLAR ALTITUDE IN DEGREES
            OHISKF = OHISKF                   $ HORIZONTAL ILLUMINANCE FROM
                                              $  OVERCAST PART OF SKY
            CHISKF = CHISKF                   $ HORIZONTAL ILLUMINANCE FROM
                                              $  CLEAR PART OF SKY
            HISUNF = HISUNF                   $ HORIZONTAL ILLUMINANCE FROM
                                              $   SUN
            ILLUM1 = DAYLIGHT-ILLUM1          $ DAYLIGHT ILLUMINANCE
                                              $  AT REF. PT 1 (FOOTCANDLES)

$ NOW OUR TABLE OF ALTITUDE AND DAYLIGHT FACTORS FROM SCALE MODEL

   CLDF1 = TABLE (0,.04) (10,.038) (45, .001) (70,.055) ..

CALCULATE   .. $ NOTE: NEXT THREE LINES MUST BEGIN IN COLUMN 7
      IDIRH = HISUNF + CHISKF       $ CLEAR SKY ILLUMINANCE
      ILLUM1 = .80*(PWL(CLDF1,PHSUND)*IDIRH + OHISKF*.019)
      END
END-FUNCTION ..
----+----1----+----2----+----3----+----4----+----5----+----6----+----7
```

Note that 0.019 is the measured daylight factor from the scale model for overcast conditions. The CLDF1 (clear day factor) tables values are from measurements at various solar altitudes. The .80 value adjusts the measured data for losses in visible light transmission through double glazing.

Figure 5. EWEB User-Defined Daylight Function for North Perimeter

In DOE-2, PWL is a built-in utility function that does a piecewise linear interpolation from a table based on the value. This routine is very useful in DOE user-defined functions providing a simple mechanism to interpolate data from a table. Writing equivalent pseudo-FORTRAN code in a user-defined function will run much more slowly, since it would be interpreted. Unfortunately, no equivalent function is available to interpolate from a two dimensional table. Such a feature would be ideal for daylighting calculations. The most general user-defined function would interpolate from a table of daylight factors based on altitude and azimuth. A two dimensional interpolation must be written in pseudo-FORTRAN and interpreted at runtime.

It is interesting to note that this technique is in fact the mechanism used internally by DOE-2 to calculate the daylighting available at any hour. Before the start of the simulation, a table of daylight factors for a window are calculated based on solar altitude and azimuth. The hourly space loop uses these precalculated tables for interpolation at simulation runtime.

Note that the DOE-2 SPACE definition in our second example contains a "dummy" window of small size. One limitation of the FUNCTION mechanism as currently implemented in DOE-2 is that a normal DOE-2 (internal) daylighting calculation must be performed to be able to use the FUNCTION. Therefore, a window (in this case a small dummy) must exist in the SPACE for DOE-2's default calculations to work. I have suggested to LBL a mechanism to disable the internal calculations if they are to be replaced anyway by a FUNCTION value. Hopefully, this feature will be added in a future revision.

Results and Conclusions

Our experience using his method for analyzing complex daylighting has been successful. Reports available from the DOE-2 simulation provide useful monthly summaries for the percent of lighting energy reduction, average daylight illuminance, hours lighting above setpoint, and glare information. Another report also depicts a summary of energy reduction by hour of day versus month. Using this information, the building designer can make better informed decisions on the daylight features such as window sizes and floor to ceiling heights and their impact on estimated energy savings. For example, the window sizes below the light shelves in the EPUD building were significantly reduced based on the results of scale models and DOE-2 simulations. The orientation of the sawtooth clerestories in the EWEB building were changed from south to north-facing.

One of the major drawbacks in using these techniques is the cost (time and dollars) of the scale building models for daylighting studies. The cost of each building model and measurement study was several thousand dollars. Although this can become a considerable expense on a small design process, these models have also proved useful in providing qualitative feedback to the design team on daylight issues. The limitation to these models is that they are not easily changed. If the scale measurements and DOE-2 results indicate that ceiling heights can be lowered, this can become a costly model change to get revised daylight factors. The ideal scheme might use an initial scale model in conjunction with some second or third generation daylight analysis program like SUPERLITE to calculate daylight factors for small changes.

Both of these buildings are being monitored over a three year period. In addition, detailed building audits are being conducted every 6 months to capture schedule information and note changes or problems with equipment. From the preliminary data collected thus far, this analysis method is most limited by the actual controls installed and operated in these buildings. Although the lighting controls in both buildings were considered reasonable state-of-the-art when bid, they should be considered primitive by microcomputer standards.

Acknowledgements

The author would like to acknowledge the assistance of Kathy Ellington, Bruce Birdsall, Ender Erdem, Fred Winkelmann, and Fred Buhl of Lawrence Berkeley Laboratory in working with the DOE-2 program and the function mechanism. The author would also like to acknowledge valuable support from T. White and G. Vincent of Bonneville Power Administration, the program managers of the Energy Edge project under which this work was funded at ODOE.

References

(1) Reynolds, J. and Baker, M.S., *An Office Building for an Electric Utility,* **Advances in Solar Energy Technology,** Volume 4, Pergamon Press (1988).

(2) Winkelmann, F. and Selkowitz, S., "Daylighting Simulation in the DOE-2 Building Energy Analysis Program," *Energy and Buildings,* Volume 8 (1985).

(3) Simulation Research Group, **DOE-2 Supplement Version 2.1C,** Lawrence Berkeley Laboratory, National Technical Information Service (May 1984).

(4) Windows and Daylighting Group, **SUPERLITE 1.0 Program Description and Summary,** Lawrence Berkeley Laboratory (January 1987).

(5) Windows and Daylighting Group, **SUPERLITE 1.0 Evaluation Manual,** Lawrence Berkeley Laboratory (January 1985).

DOE-2.1D Basic Manual

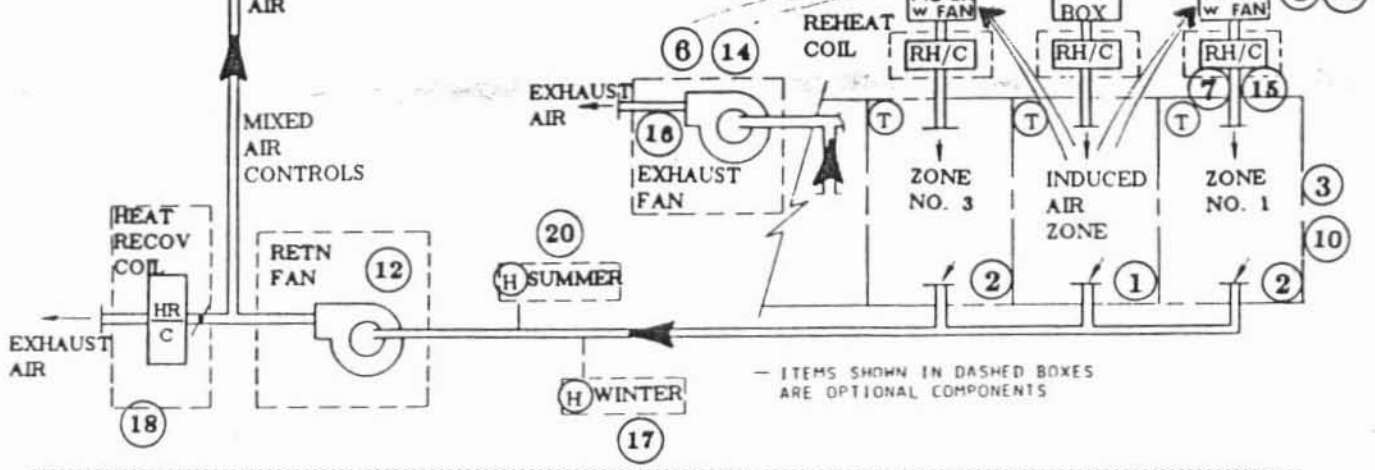
The Simulation Research Group is in the process of preparing a *Basic Manual*, which will cover the essentials of preparing standard DOE-2 inputs. The *Basic Manual* is scheduled for completion mid-1990. It will be a stand-alone piece of documentation directed at the new user. Availability of the Manual will be announced in the User News; it will be offered for sale through the National Technical Information Service.

We are planning to excerpt sections from the *Basic Manual* chapter on System Types in this issue and in the next two issues of the User News. For each system type the following information will be presented: (1) a short description of the system; (2) a schematic diagram of the system, on which we have keyed the system components to their associated keywords using circled numbers; (3) a suggested minimal input for a 1-zone building; and (4) a listing of additional capabilities for the system and the keywords that enable them. In this issue we present system types PIU, HP, and VAVS.

Powered Induction Unit (PIU)

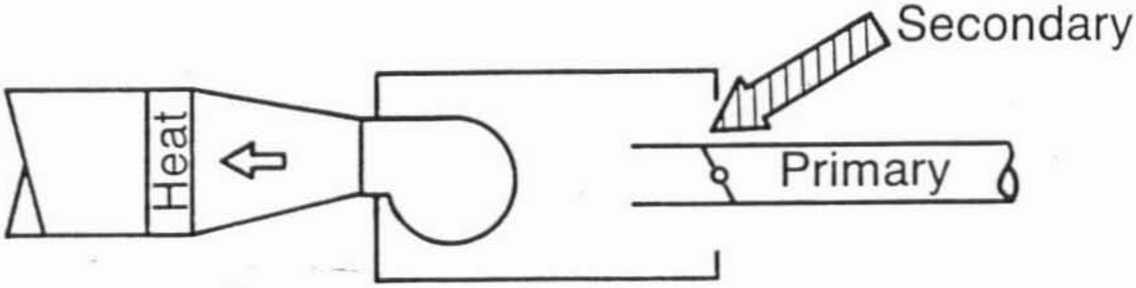
The basic Powered Induction Unit (PIU) system, illustrated below, consists of a central air-handling unit with filter (not shown), cooling and optional heating coils, and a draw-through type supply air fan. A return air fan is also usually used. Exhaust fan(s) are optional for any or all zones.

Powered induction boxes are available in two configurations: *series* and *parallel*.



The suggested minimal input for PIU with economizer is shown for *series* type units configured like the sketch below. Note: there must be more than one zone.

::



Series PIU

::

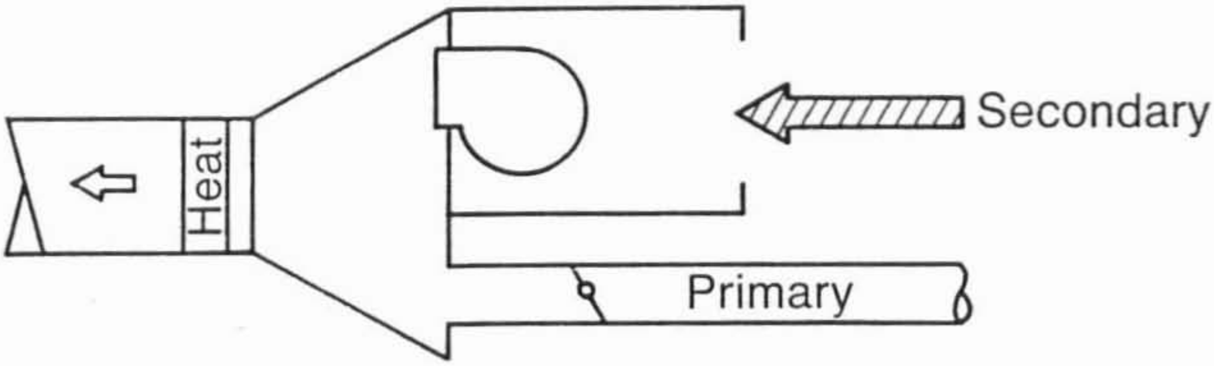
```
INPUT SYSTEMS     ..
                  $ SYSTEMS SCHEDULES

FANS-ON =    SCHEDULE THRU DEC 31 (WD)  (1,7)(0) (8,18)(1)
                                        (19,24)(0)
                                  (WEH) (1,24)(0)   ..

COOLSETPT = SCHEDULE THRU DEC 31 (WD)   (1,7)(99) (8,18)(76)
                                        (19,24)(99)
                                  (WEH) (1,24)(99)   ..
HEATSETPT = SCHEDULE THRU DEC 31 (WD)   (1,7)(55) (8,18)(72)
                                        (19,24)(55)
                                  (WEH) (1,24)(55)   ..

CORE = ZONE     DESIGN-HEAT-T     =   72
   1            DESIGN-COOL-T     =   74
                HEAT-TEMP-SCH     =   HEATSETPT
                COOL-TEMP-SCH     =   COOLSETPT  3
                TERMINAL-TYPE     =   SVAV 4
                CFM/SQFT          =   .7
                OA-CFM/PER        =   15 .. 5
OFFICE = ZONE   LIKE CORE
   2            TERMINAL-TYPE     =   SERIES-PIU
                ZONE-FAN-RATIO    =   1
                ZONE-FAN-KW       =   .00033  6
                INDUCED-AIR-ZONE  =   CORE 1
                REHEAT-DELTA-T    =   55 .. 15
```

Example input is shown for *parallel* type units like the sketch below:



Parallel PIU

```
INPUT SYSTEMS   ..
                 $ SYSTEMS SCHEDULES

FANS-ON =     SCHEDULE THRU DEC 31 (WD)  (1,7)(0) (8,18)(1)
                                         (19,24)(0)
                                   (WEH) (1,24)(0)  ..

COOLSETPT = SCHEDULE THRU DEC 31 (WD)  (1,7)(99) (8,18)(76)
                                       (19,24)(99)
                                 (WEH) (1,24)(99)  ..
HEATSETPT = SCHEDULE THRU DEC 31 (WD)  (1,7)(55) (8,18)(72)
                                       (19,24)(55)
                                 (WEH) (1,24)(55)  ..

START-Z=FAN = SCHEDULE THRU DEC 31  (WD) (1,7) (55) (8,18) (73) (19,24) (55)
                                    (WEH) (1,24) (55) ..

CORE = ZONE        DESIGN-HEAT-T    =  72
   (1)             DESIGN-COOL-T    =  74
                   HEAT-TEMP-SCH    =  HEATSETPT
                   COOL-TEMP-SCH    =  COOLSETPT  (3)
                   TERMINAL-TYPE    =  SVAV (4)
                   OA-CFM/PER       =  15 .. (5)
```

```
OFFICE = ZONE         LIKE CORE
   (2)                TERMINAL-TYPE        =   PARALLEL-PIU
                      ZONE-FAN-RATIO       =   .8      (6)
                      ZONE-FAN-KW          =   .00033
                      ZONE-FAN-T-SCH       =   START-Z-FAN (3)
                      INDUCED-AIR-ZONE     =   CORE (1)
                      REHEAT-DELTA-T       =   55 .. (15)

AC-SYST = SYSTEM      SYSTEM-TYPE          =   PIU
                      MAX-SUPPLY-T         =   110 (7)
                      HEAT-SET-T           =   70 (8)
                      MIN-SUPPLY-T         =   55 (9)
                      NIGHT-CYCLE-CTRL     =   ZONE-FANS-ONLY (10)
                      FAN-SCHEDULE         =   FANS-ON (11)
                      RETURN-STATIC        =   1.0     (12)
                      RETURN-EFF           =   .55
                      OA-CONTROL           =   TEMP    (13)
                      ECONO-LIMIT-T        =   68
                      MIN-CFM-RATIO        =   .3 (14)
                      ZONE-NAMES           =   (OFFICE) .. (2)

END ..
COMPUTE SYSTEMS ..
INPUT PLANT ..
PLANT-REPORT SUMMARY = (BEPS) ..

SHW = PLANT-EQUIPMENT    TYPE = DHW-HEATER       SIZE = -999 ..
HWG = PLANT-EQUIPMENT    TYPE = HW-BOILER        SIZE = -999 ..
CHR = PLANT-EQUIPMENT    TYPE = HERM-REC-CHLR    SIZE = -999 ..

PLANT-PARAMETERS    BOILER-FUEL = NATURAL-GAS
                    HERM-REC-COND-TYPE = AIR ..

END ..
COMPUTE PLANT ..
```

ADDITIONAL CAPABILITIES for PIU system:

1) To enable an exhaust fan add the keywords EXHAUST-CFM = Value (CFM) and EXHAUST-KW = Value (.0001 is typical) to the ZONE keyword list. (16)

2) To enable a humidifier which requires heat to evaporate water into the air add MIN-HUMIDITY = Value (25% is typical) to the SYSTEM keyword list. (17)

3) To enable heat recovery to exchange relief air heat with outside air heat add RECOVERY-EFF = Value (0.6 is typical) to the SYSTEM keyword list. (18)

4) To disable the economizer change the OA–CONTROL = TEMP to OA–CONTROL = FIXED. (19)

5) To reset the supply air as a function of outside air temperature see an example of this control in the SAMPLE RUN BOOK, 31-Story Office Building, Run 1.

6) To enable control of maximum humidity whenever the supply air temperature is reset, insert MAXIMUM–HUMIDITY = Value (60% is allowed in the new ASHRAE 90.1P Standards) in the SYSTEM keyword list. (20)

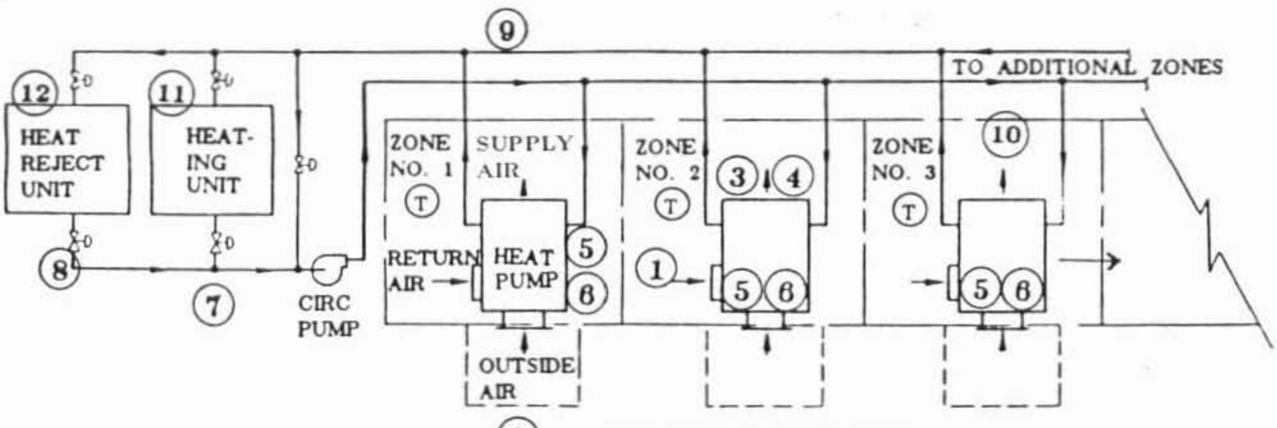
7) Simulating baseboard heat in lieu of or in addition to reheat coils is demonstrated in the SAMPLE RUN BOOK, 31-Story Office Building, Runs 2 and 3.

8) To enable variable speed control of the fan motor, insert FAN–CONTROL = SPEED in the SYSTEM keyword list. (21)

Unitary Hydronic Heat Pump System (HP)

The Unitary Hydronic Heat Pump System, illustrated below, provides heating and cooling for a number of individually controlled zones by operation of heat pump units located in each space to be conditioned. Each heat pump unit may provide a fixed quantity of outside air ventilation, or merely recirculate conditioned air. Each heat pump consists of a refrigerant compressor, a room air-to-refrigerant heat exchanger, a working fluid-to-refrigerant heat exchanger (connected to the pipe loop), controls to switch the evaporating and condensing functions from one heat exchanger to the other, a supply air fan, and a two-set-point ZONE thermostat. When the heat pump is in the room heating mode of operation, the room air-to-refrigerant heat exchanger is used for refrigerant condensing. In the room cooling mode, this same heat exchanger is used for refrigerant evaporating. Each heat pump provides dehumidification in the cooling mode but has no dehumidification control.

Temperature is controlled in each zone by on-off operation of the heat pump unit (fan and compressor). The type of thermostat used for this system has two individual set points. The heat pump unit provides cooling when space temperature increases to the upper set point, and heating when the space temperature falls to the lower set point; it does not operate when space temperature is between set points. If outside air is specified the fan operates continuously; otherwise, the fan cycles on and off with the refrigeration compressor. A piping system with circulating fluid is connected to the water-to-refrigerant heat exchanger in the heat pump. The circulating fluid absorbs heat from those units that are operating in the cooling mode, and gives up heat to those units that are operating in the heating mode. Because some zone units may be cooling, while others are heating, the temperature of the fluid circulating will depend on the relative quantities of each. When cooling demand exceeds heating demand and the fluid temperature increases to the highest allowable value (see keyword MAX-FLUID-T in the SYSTEM-FLUID instruction), heat is dissipated to the atmosphere through an evaporative cooler (or a cooling tower). When heating demand exceeds cooling demand and the fluid temperature decreases to the minimum allowable value (see keyword MIN-FLUID-T in the SYSTEM-FLUID instruction), heat is added from a boiler or other heat source. No heat is added or rejected when heating and cooling requirements balance. The most common hydronic heat pump systems maintain the water in the circulating loop between 60°F and 90°F. The heat rejection unit (evaporative condenser or cooling tower), heating unit, and circulating pump are simulated by the PLANT program.



ITEMS SHOWN IN DASHED BOXES ARE OPTIONAL COMPONENTS

SUGGESTED MINIMAL INPUT for HP

```
INPUT SYSTEMS  ..
                     $ SYSTEMS SCHEDULES

FANS-ON =    SCHEDULE THRU DEC 31 (WD)   (1,7)(0) (8,18)(1)
                                         (19,24)(0)
                                  (WEH)  (1,24)(0)   ..

COOLSETPT = SCHEDULE THRU DEC 31 (WD)    (1,7)(99) (8,18)(76)
                                         (19,24)(99)
                                  (WEH)  (1,24)(99)  ..
HEATSETPT = SCHEDULE THRU DEC 31 (WD)    (1,7)(55) (8,18)(72)
                                         (19,24)(55)
                                  (WEH)  (1,24)(55)  ..

OFFICE = ZONE       DESIGN-HEAT-T      =   72
                    DESIGN-COOL-T      =   74
                    HEAT-TEMP-SCH      =   HEATSETPT  (1)
                    COOL-TEMP-SCH      =   COOLSETPT
                    OA-CFM/PER         =   15 .. (2)
AC-SYST = SYSTEM    SYSTEM-TYPE        =   HP
                    MAX-SUPPLY-T       =   110 (3)
                    MIN-SUPPLY-T       =   55 (4)
                    NIGHT-CYCLE-CTRL   =   CYCLE-ON-ANY (5)
                    FAN-SCHEDULE       =   FANS-ON (6)
                    MIN-FLUID-T        =   60 (7)
                    MAX-FLUID-T        =   90 (8)
                    FLUID-HEAT-CAP     =   (estimated lbs of water in system
                                           + that in any storage tank) (9)
                    ZONE-NAMES         =   (OFFICE) .. (10)
END ..
COMPUTE SYSTEMS ..
INPUT PLANT ..
PLANT-REPORT SUMMARY = (BEPS) ..

SHW = PLANT-EQUIPMENT   TYPE = DHW-HEATER    SIZE = -999 ..
HWG = PLANT-EQUIPMENT   TYPE = HW-BOILER     SIZE = -999 .. (11)
WCL = PLANT-EQUIPMENT   TYPE = COOLING-TWR   SIZE = -999 .. (12)

PLANT-PARAMETERS   BOILER-FUEL = NATURAL-GAS ..
END ..
COMPUTE PLANT ..
```

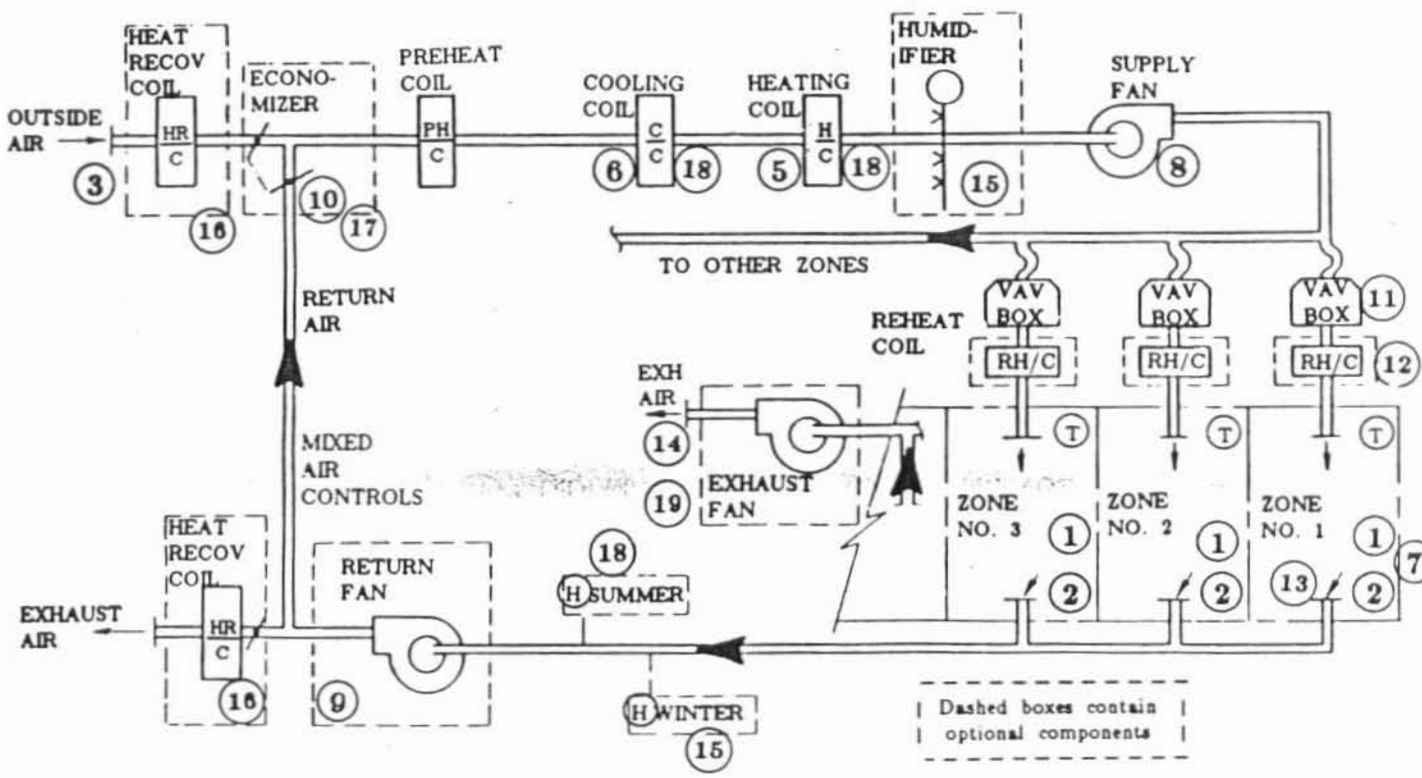
ADDITIONAL CAPABILITY for HP system:

1) To enable an exhaust fan add the keywords EXHAUST-CFM = Value (CFM) and EXHAUST-KW = Value (.0001 is typical) to the ZONE keyword list (not shown).

Variable-Volume Fan System w/Optional Reheat (VAVS)

The Variable-Volume Fan System is illustrated in the schematic below. In its most basic configuration, it consists of a central air-handling unit with filter (not shown), cooling and optional heating coils, and a draw-through type supply air fan. Exhaust fan(s) are optional for any or all zones. A duct system distributes supply air (at a temperature determined by the user) to variable-air volume (VAV) terminal units, located in the zones being served.

The VAV boxes (controlled by a room thermostat) vary the amount of primary air to the space to control temperature. When the space demands peak cooling, the VAV box allows maximum air flow. As space cooling requirements diminish, the primary air flow to the space is reduced proportionately to a specified minimum flow rate. If less cooling is required than that given at minimum air flow, the reheat coil is activated (if specified). When in the heating mode, the supply air flow rate is held at a constant value equal to MIN-CFM-RATIO. The supply air flow rate will rise above the MIN-CFM-RATIO only *if* the user has set THERMOSTAT-TYPE = REVERSE-ACTION. The Btu equivalent of the moisture that is added to the air stream, to maintain a minimum humidity, is passed to the PLANT program as a heating load.



SUGGESTED MINIMAL INPUT for VAVS

```
INPUT SYSTEMS ..
                    $ SYSTEMS SCHEDULES

FANS-ON =    SCHEDULE THRU DEC 31 (WD)  (1,7)(0) (8,18)(1)
                                        (19,24)(0)
                                  (WEH) (1,24)(0)  ..

COOLSETPT = SCHEDULE THRU DEC 31 (WD)   (1,7)(99) (8,18)(76)
                                        (19,24)(99)
                                  (WEH) (1,24)(99)  ..
HEATSETPT = SCHEDULE THRU DEC 31 (WD)   (1,7)(55) (8,18)(72)
                                        (19,24)(55)
                                  (WEH) (1,24)(55)  ..

OFFICE = ZONE      DESIGN-HEAT-T       =  72
                   DESIGN-COOL-T       =  74
                   HEAT-TEMP-SCH       =  HEATSETPT
                   COOL-TEMP-SCH       =  COOLSETPT     1
                   THERMOSTAT-TYPE     =  REVERSE-ACTION  2
                   OA-CFM/PER          =  15 ..  3
AC-SYST = SYSTEM   SYSTEM-TYPE         =  VAVS
                   MAX-SUPPLY-T        =  110  4
                   HEAT-SET-T          =  70   5
                   MIN-SUPPLY-T        =  55  6
                   NIGHT-CYCLE-CTRL    =  CYCLE-ON-FIRST  7
                   FAN-SCHEDULE        =  FANS-ON  8
                   RETURN-STATIC       =  1.0
                   RETURN-EFF          =  .55   9
                   OA-CONTROL          =  TEMP
                   ECONO-LIMIT-T       =  68    10
                   MIN-CFM-RATIO       =  .3  11
                   REHEAT-DELTA-T      =  55  12
                   ZONE-NAMES          =  (OFFICE) ..  13
END ..
COMPUTE SYSTEMS ..
INPUT PLANT ..
PLANT-REPORT SUMMARY = (BEPS) ..

SHW = PLANT-EQUIPMENT    TYPE = DHW-HEATER       SIZE = -999 ..
HWG = PLANT-EQUIPMENT    TYPE = HW-BOILER        SIZE = -999 ..
CHR = PLANT-EQUIPMENT    TYPE = HERM-REC-CHLR    SIZE = -999 ..

PLANT-PARAMETERS   BOILER-FUEL = NATURAL-GAS
                   HERM-REC-COND-TYPE = AIR ..
END ..
COMPUTE PLANT ..
```

ADDITIONAL CAPABILITIES for VAVS system:

1) To enable an exhaust fan add the keywords EXHAUST–CFM = Value (CFM) and EXHAUST–KW = Value (.0001 is typical) to the ZONE keyword list. (14)

2) To enable a humidifier which requires heat to evaporate water into the air add MIN–HUMIDITY = Value (25% is typical) to the SYSTEM keyword list. (15)

3) To enable heat recovery to exchange relief air heat with outside air heat add RECOVERY–EFF = Value (0.6 is typical) to the SYSTEM keyword list. (16)

4) To disable the economizer change the OA–CONTROL = TEMP to OA–CONTROL = FIXED. (17)

5) To reset the supply air as a function of outside air temperature see example of this control as shown in the SAMPLE RUN BOOK, 31-Story Office Building, Run 1.

6) To enable control of maximum humidity whenever the supply air temperature is reset, insert MAXIMUM–HUMIDITY = Value (60% is allowed 90.1P) in the SYSTEM keyword list. (18)

7) Simulating baseboard heat in lieu or in addition to reheat coils is demonstrated in the SAMPLE RUN BOOK, 31-Story Office Building, Run 1.

8) To enable variable speed control of the fan motor, insert FAN–CONTROL = SPEED in the SYSTEM keyword list. (19)